AIRS/AMSU/HSB Version 5 Modification of Algorithm to Account for Increased NeDT in AMSU Channel 4

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Introduction

The AIRS Science Team Version 5 AIRS/AMSU retrieval algorithm includes use of observations of AMSU-A channel 4. This channel had an instrumental NEDT of 0.14K at launch. AMSU-A channel 4 NEDT remained stable at this value until August 2007, at which time the channel noise began to increase. The Goddard DAAC operational AIRS/AMSU Version 5 retrieval algorithm assumes the at-launch value for AMSU-A channel 4 NEDT. As channel 4 noise increased from this value, the performance of the Version 5 retrieval algorithm began to degrade, both in terms of the percentage of acceptable retrievals as well as the accuracy of the accepted retrievals.

Figure 1: Yield as a function of AMSU Channel 4 NeDT.

The figure shows the decrease in fraction of daily Level 2 retrieval yield at 100mb that occurred as a result of the increase in AMSU channel 4 NeDT.
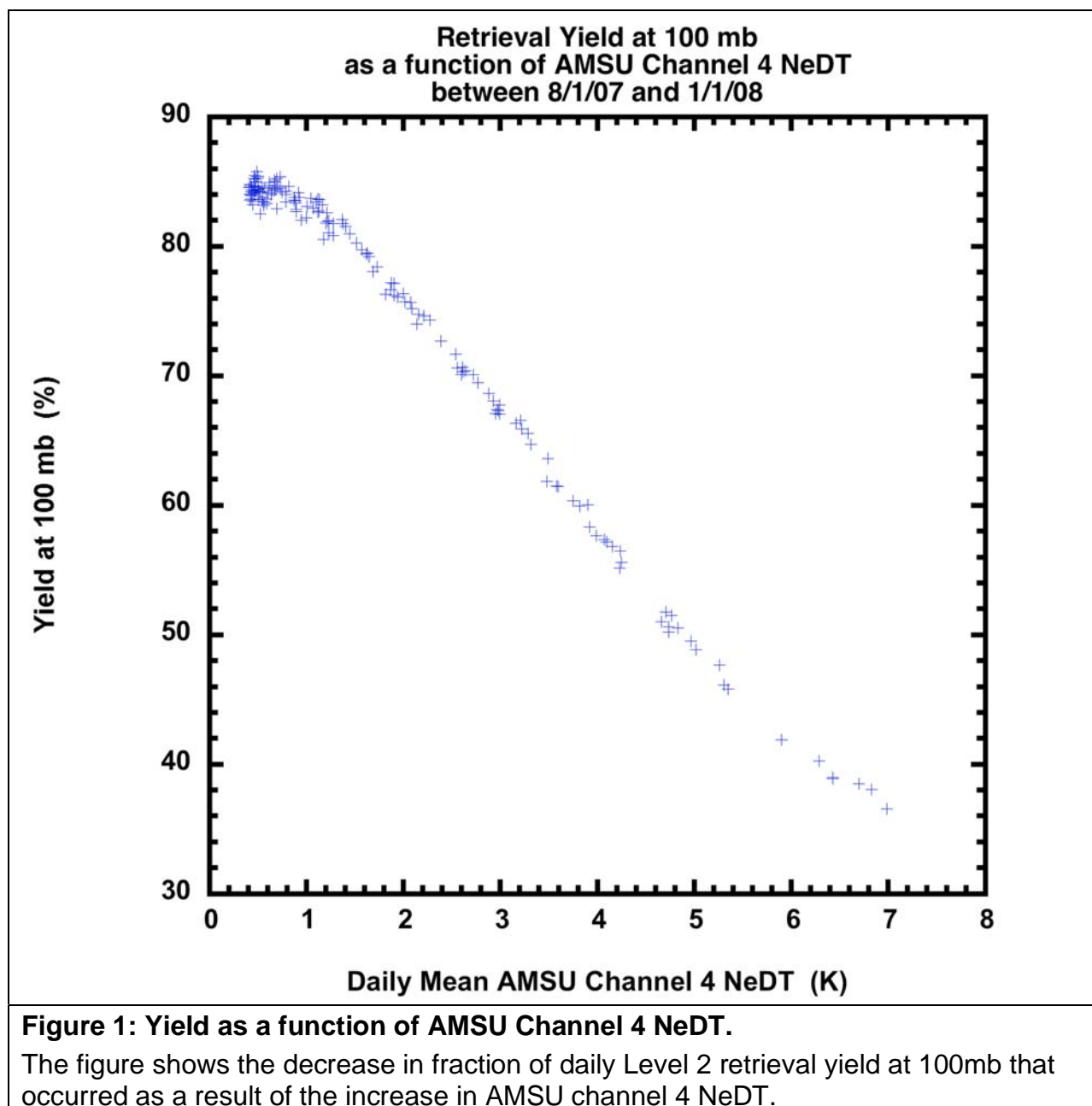
V5 Algorithm Modification for Increased AMSU Channel 4 NeDT

Figure 1 shows the dramatic drop in daily yield of Level 2 retrievals from August, 2007 (before AMSU channel 4 began to degrade) through December, 2007. The steady increase in NeDT resulted in increasingly larger number of microwave stage retrievals to be rejected by the quality control built into the Version 5 retrieval algorithm.

The AIRS Science Team weighed options for modification to the Version 5 AIRS/AMSU retrieval algorithm (a) to improve retrieval accuracy as the noise in AMSU-A channel 4 degraded, and (b) to closely match Version 5 results obtained when AMSU channel 4 was performing nominally. Two different options were considered. Option 1 was to keep the Version 5 retrieval algorithm otherwise identical to what it had been, but to eliminate the use of AMSU-A channel 4 from any of the retrieval steps. Option 2 was to attempt to predict the AMSU-A channel 4 observed brightness temperature, based on the observations in the remaining AMSU-A channels. This predicted channel 4 brightness temperature, Θ_4^P, would then be used in the otherwise unchanged Version 5 AIRS/AMSU retrieval algorithm in place of the observed AMSU-A channel 4 brightness temperature Θ_4^{OBS}. Both options performed well, but Option 2 performed somewhat better in terms of overall accuracy of the results, and more importantly, continuity of the Version 5 data product record once AMSU channel 4 began to degrade. We assessed the important issue of continuity by comparing products obtained by the Version 5 retrieval algorithm, using Θ_4^{OBS} on the one hand, and Θ_4^P on the other, when AMSU-A channel 4 was performing nominally. As a result of this comparison, Option 2, using predicted values of AMSU channel 4 brightness temperatures in an otherwise unchanged AIRS/AMSU Version 5 retrieval algorithm, was selected for use in future Version 5 processing of AIRS/AMSU data.

Previously processed AIRS/AMSU data during the period from October 1, 2007 to March 2, 2008 will be reprocessed with the modified algorithm and the data products replaced. Beginning on March 3, 2008 all forward processing is via the V5.2.2 algorithm. Thus the Version 5 Level 2 and Level 3 data products previous to October 1,2007 will remain as V5.0.14. After reprocessing has been completed, the Version 5 Level 2 and Level 3 data products will be the result of V5.2.2 processing from October 1,2007 onward.

The success of Option 2 was critically dependent on the ability to predict AMSU channel 4 observations from those of the other AMSU-A channels. This methodology is described in the next section.

Prediction of AMSU-A channel 4 brightness temperatures from other AMSU-A channel observations

While AMSU-A contains 15 independently measured brightness temperatures, there are less than 15 independent pieces of information regarding surface and atmospheric

geophysical parameters contained in those observations. As a result, much of the geophysical information contained in radiance observations of a given channel can be ascertained by observations in the remaining channels. Using standard linear regression techniques, we predict a brightness temperature for AMSU channel 4 according to the following form:

$$\left(\frac{\Theta_4^P - \overline{\Theta}_4^P}{NEDT_4}\right) = \sum_{\substack{i=1,2,3,5,6, \\ 8 \to 15}} A_i \left(\frac{\Theta_i - \overline{\Theta}_i}{NEDT_i}\right) \tag{1}$$

In the above Equation, Θ_i, is the brightness temperature of AMSU-A channel **i**, for all channels excluding both channel 4 and channel 7, which was deemed too noisy at launch to be incorporated into the retrieval algorithm. $NEDT_i$ is the at launch noise in brightness temperature units of channel **i**, $\overline{\Theta}_i$ is the mean value of Θ_i (including i=4) over some ensemble, and A_i is a vector to be determined. Given the vectors A_i and $\overline{\Theta}_i$, an observation of channel 4 can be predicted based on collocated observations in the remaining channels using Equation 1.

Determination of the vectors A_i and $\overline{\Theta}_i$

The vectors A_i and $\overline{\Theta}_i$ were determined via simulation using radiative transfer calculations for an ensemble of **N** geophysical states $X^{n=1,N}$, where X^n was a one day global ensemble of all retrieved geophysical states for all **N** cases in which a satisfactory AMSU-A microwave product retrieval was performed (**N** $\approx$ 230000 cases). For each of these states X^n, derived from AMSU observations at its given microwave zenith angle, the expected brightness temperatures for all AMSU channels Θ_i^n, observed at the appropriate satellite zenith angle, was computed using the AIRS Science Team AMSU-A Radiative Transfer Algorithm. The vector A_i was determined from the **N** linear Equations:

$$\left(\frac{\Theta_4^P - \overline{\Theta}_4^P}{NEDT_4}\right) = \sum A_i \left(\frac{(\Theta_i^n + \Delta\Theta_i^n) - \overline{\Theta}_i}{NEDT_i}\right) \tag{2}$$

by minimizing the RMS difference between the right and left hand sides of Equation 2. In Equation 2, random measurement noise $\Delta\Theta_i$ consistent with $NEDT_i$ was added to the computed brightness temperatures on the right side of the Equation, but not on the left.

Generation of Θ_4^P based on actual AMSU-A observation Θ_i^{OBS}

AMSU-A brightness temperatures observations are affected by channel and angle dependent antenna pattern distortions $\delta\Theta_{i,\ell}$ where ℓ is the beam position going from 1-30 across an AMSU-A scan line. These values, $\delta\Theta_{i,\ell}$, also referred to as microwave tuning coefficients, are described and shown in the AIRS Science Team Algorithm Theoretical Basis Document:

http://eospso.gsfc.nasa.gov/eos_homepage/for_scientists/atbd/viewInstrument.php?instrument=22

They are determined by finding the mean angle dependent ensemble differences between observed brightness temperatures $\Theta_{i,\ell}^{OBS}$ and those computed from the "true" state, $\Theta_{i,\ell}^{comp}$. These tuning coefficients $\delta\Theta_{i,\ell}$ are subtracted from observed AMSU-A brightness temperatures $\Theta_{i,\ell}$ before the AMSU observations are used in the AIRS/AMSU physical retrieval steps.

In Figure 2 the dashed red line an example of the tuning coefficients $\delta\Theta_{4,\ell}$ used for channel 4. It can be seen that the antenna pattern distortion makes the observed values of AMSU-A channel 4 colder than they should be by values ranging from about 1.2K near nadir to values greater than 2.0K at large satellite zenith angles. Similar antenna pattern distortions are observed in the other AMSU-A channels. These antenna pattern distortions on the AMSU-A observations, $\delta\Theta_{i,\ell}$, must be subtracted from the AMSU-A observations before they can be used to predict channel 4 observations. Therefore, we attempted to predict AMSU channel 4 based on AMSU observations according to Equation 3a, rather than Equation 2.

$$\left(\frac{\Theta_4^P - \overline{\Theta}_4^P}{NEDT_4}\right) = \sum A_i\left(\frac{(\Theta_i - \delta\Theta_i) - \overline{\Theta}_i}{NEDT_i}\right)$$

(3a)

We refer to Θ_4^P derived using Equation 3a as "unadjusted" Θ_4^P.

Figure 2 shows the global mean (solid red line) and standard deviation (solid black line) of $\Theta_{4,\ell}^{OBS} - "unadjusted"\,\Theta_{4,\ell}^P$ as a function beam position ℓ. Also shown is the channel 4 noise $NEDT_4$ (dashed black line). The standard deviation of $\left(\Theta_{4,\ell}^{OBS} - \Theta_{4,\ell}^P\right)$ cannot be lower than $NEDT_4$. The solid black line shows that at most beam positions, "unadjusted" Θ_4^P agrees with Θ_4^{OBS} on the order of 0.5K up to a beam position dependent bias. This indicates that the methodology used to predict AMSU channel 4 from the other AMSU observations is performing extremely well, giving an effective noise to Θ_4^P of the order of 0.5K. We did not change $NEDT_4$ in the retrieval algorithm because we did not want to change anything so as to minimize any changes to the

retrieved products when Θ_4^P is used in place of Θ_4^{OBS}. The ability to predict Θ_4 to within a standard deviation of 0.5K from its observed value also indicates that AMSU channel 4 is indeed providing very little information about surface and atmospheric conditions not already contained in the remaining AMSU-A observations.

While the beam dependent standard deviation of $\left(\Theta_4^{OBS} - \Theta_4^P\right)$ is small, there remains a systematic beam dependent bias, $\Delta\Theta_{4,\ell}^P$ which is similar in shape to the empirical tuning curve $\delta\Theta_{4,\ell}$. This is not totally unexpected and is a residual result of the angle dependent distortions in the other AMSU-A channels. Therefore, to make Θ_4^P "look like" Θ_4, we must add this beam dependent bias $\Delta\Theta_{4,\ell}^P$ from the "unadjusted" $\Delta\Theta_{4,\ell}^P$ given in Equation 3a. Consequently, the appropriate value of Θ_4^P to be used subsequently in the retrieval process in place of Θ_4^{OBS} is computed according to

$$\left(\frac{\Theta_4^P - \overline{\Theta}_4^P}{NEDT_4}\right) = \sum_i A_i \left(\frac{\left(\Theta_{i,\ell}^{OBS} - \delta\Theta_i\right) - \overline{\Theta}_i}{NEDT_i}\right) + \Delta\Theta_{4,\ell}^P$$
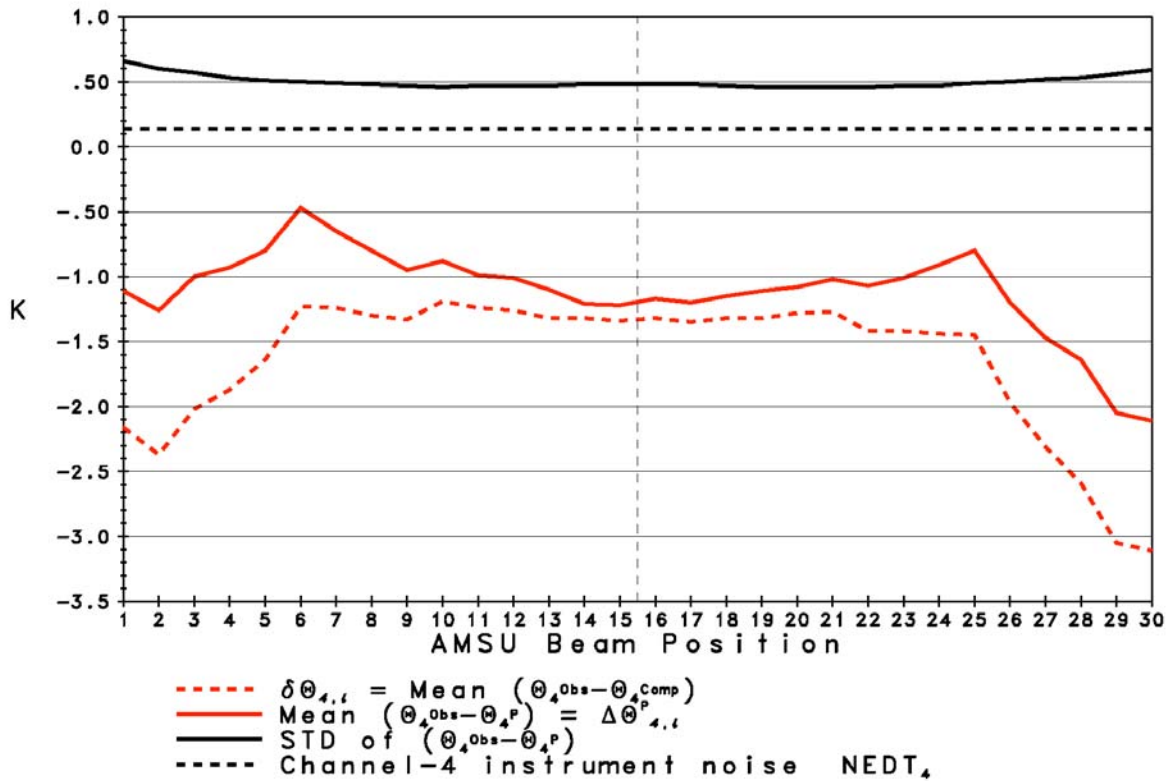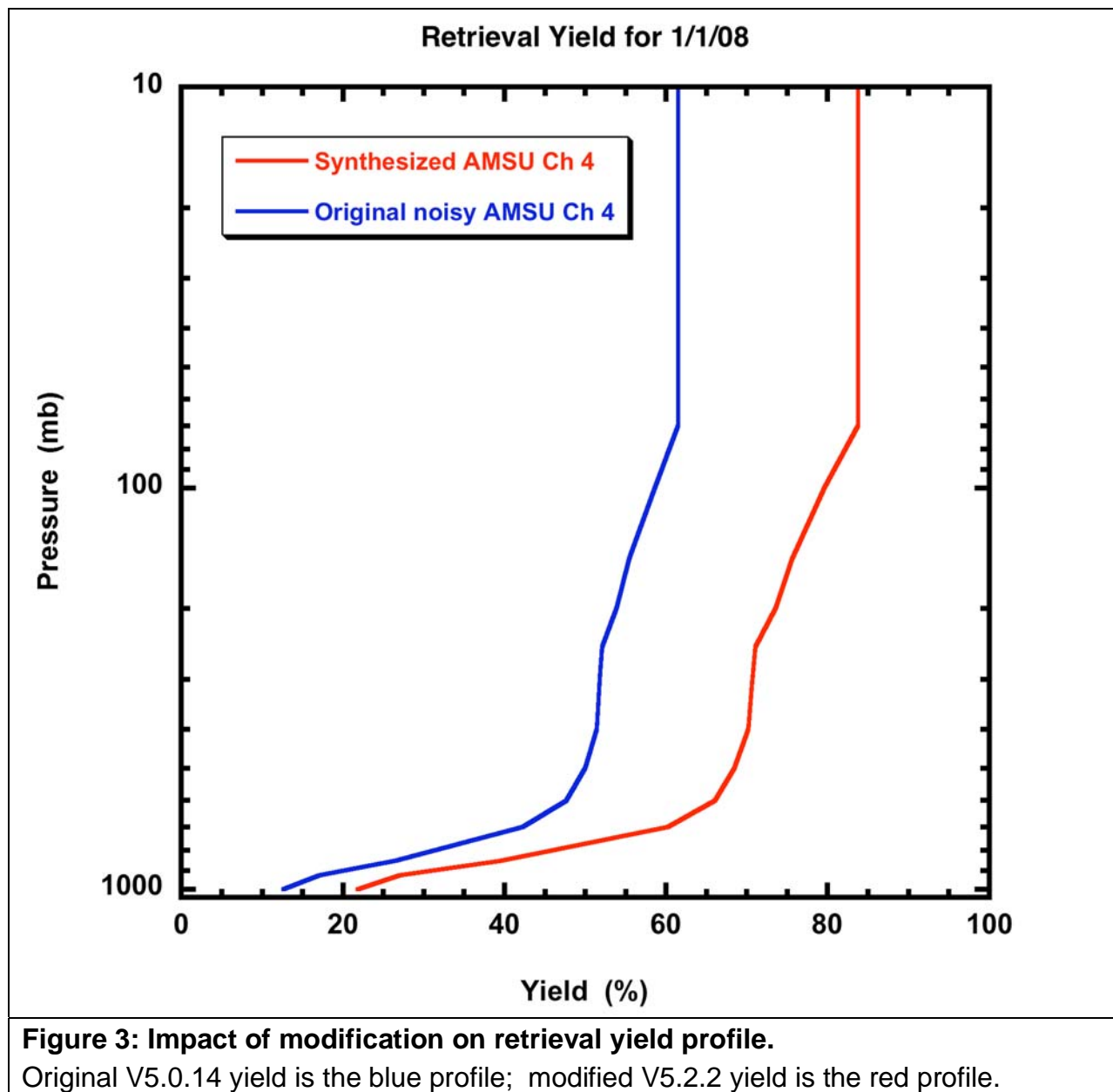
(3b)

Figure 2: Global comparison of "unadjusted Θ_4^P and observed Θ_4.
As a function of cross-track AMSU beam position. Nadir is between 15 and 16.

Comparison of V5.0.14 and V5.2.2 Retrieval Results

Version 5.0.14 data products are derived by means of the original V5 algorithm. Version 5.2.2 data products (beginning October 1, 2007) are derived by means of the V5 algorithm that makes use of the predicted AMSU-A channel 4 brightness temperatures.

Figure 3: Impact of modification on retrieval yield profile.
Original V5.0.14 yield is the blue profile; modified V5.2.2 yield is the red profile.

By January 1, 2008 the increase in AMSU-A channel 4 NeDT had significantly degraded the retrieval yield. Figure 3 shows the recovery of yield as a function of altitude on that

date upon inclusion of the modification to predict the AMSU-A channel 4 brightness temperatures.
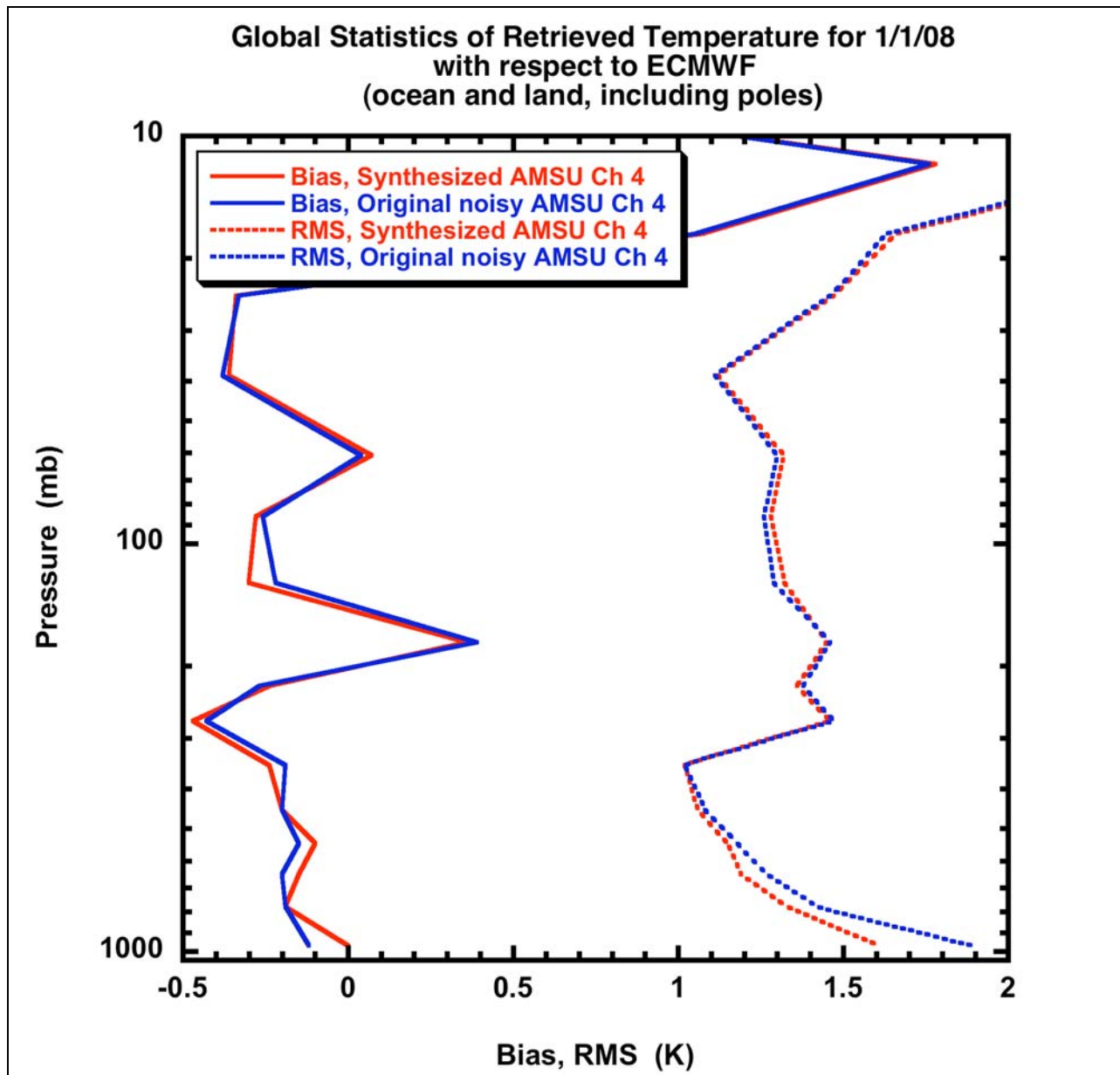

Figure 4: Impact of modification on global temperature retrieval statistics.
Original V5.0.14 yield is the blue profile; modified V5.2.2 yield is the red profile. Solid lines are the bias with respect to ECMWF. Dashed lines are the RMS difference with respect to ECMWF. Recall from Figure 3 that the number of retrievals included in the red profiles are greater than the number of retrievals included in the blue profiles by up to 40%.

Figure 4 shows the global retrieved temperature statistics with respect to ECMWF forecast before and after modifying the algorithm to make use of the predicted AMSU-A channel 4 brightness temperatures. The retrieval statistics have improved at the same time as the yield has increased.

AMSU-A channel 4 aids the cloud-clearing in the lower atmosphere. AIRS retrievals are rejected as being too cloudy once the total cloud fraction within the AMSU-A field-of-view exceeds 80%. We find that the fraction of accepted retrievals begins to fall when the total cloud fraction exceeds 60%.

Figure 5 compares the temperature profile retrieval results in the Level 2 product for V5.0.14 and V5.2.2 when applied to early mission data (September 6, 2002), a time at which AMSU-A channel 4 was performing with nominal NeDT. It shows the global average difference between the temperature profiles retrieved by employing the original and modified algorithms as a function of total cloud fraction.

The profiles shown in Figure 5 are the result of averaging the difference of the support product temperature profiles resulting from the two algorithms down to the level of NGoodSup. The yield decreases with decreasing altitude, thus the number of samples averaged decreases as the surface is approached.
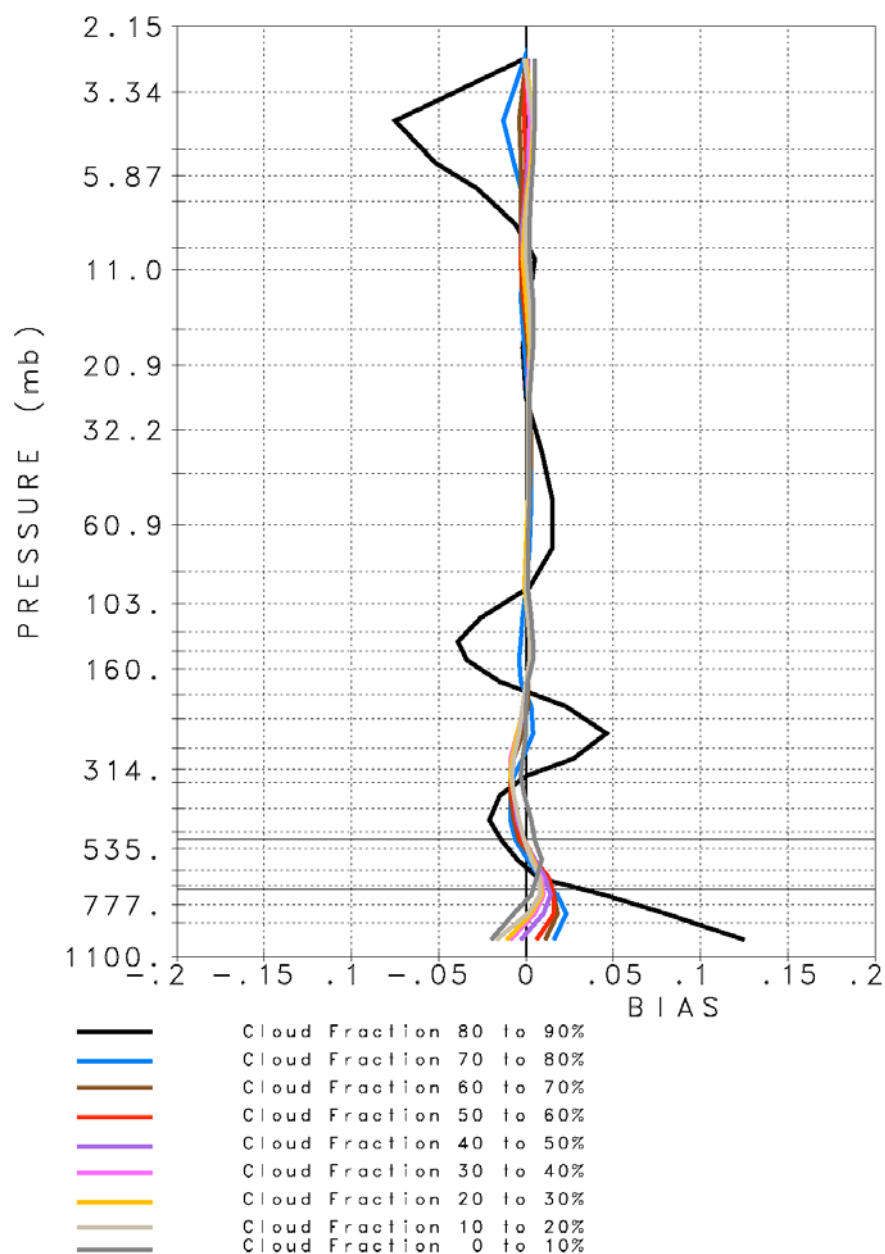
Figure 5: Comparison of V5.0.14 and V5.2.2 temperature profiles as a function of cloud fraction. Bias (V5.2.2 – V5.0.14) is °K.

Retrievals were performed for the data taken September 6, 2002 using both the original retrieval algorithm and the algorithm which includes the AMSU-A channel 4 predicted brightness temperatures. The data are from early in the mission, when AMSU-A channel 4 was operating at nominal NeDT. The Level 2 support product profiles down to NGoodSup from the two runs were differenced and averaged. The resulting difference profile is shown in this figure as a function of cloud fraction. AIRS data users are advised to make use of the quality control factors (e.g., PBest and PGood and other Qual_*).